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Lead in Milk and Infant Blood: A Dose-Response Model

MICHAEL RABINOWITZ, Ph.D.
ALAN LEVITON, M.D.
Mental Retardation Unit
Children's Hospital
and
Department of Neurology
Harvard Medical School
Boston, Massachusetts
HERBERT NEEDLEMAN, M.D.
Department of Psychiatry
Pittsburgh Children's Hospital
University of Pittsburgh
Pittsburgh, Pennsylvania

ABSTRACT. As part of a longitudinal study of the sources and developmental effects of current urban lead exposure, lead was measured in tap water from the homes of 249 infants, in 100 breast milk samples, and in 73 samples of the infant formula used by non-nursing mothers. Also, the blood lead levels of the infants who received these fluids were determined at birth and at 6 months of age. Among the infants who were breast fed, the lead content of their milks correlated very well with their 6-month blood lead levels ($r = .42$, $P = .0003$). The mean lead content of infant formulas and breast milk were not significantly different, nor was the blood lead of children fed one or the other. Lead levels in maternal milk correlated poorly with umbilical cord blood lead ($r = .18$, $P = .10$). Tap water and infant blood lead levels correlated minimally ($r = .11$, $P = .10$). Since milk represents much of the diet of young infants and because breast milk lead levels are stable, it is possible to relate blood lead and daily dosage in this population.

THE QUESTION of the magnitude and sources of lead exposure in early childhood is becoming more pressing as evidence accumulates that current community exposure to lead is resulting in harmful effects. The incidence of malformations is higher among those with relatively elevated cord blood lead.[1] At 1 yr of age, children who have higher umbilical cord blood lead levels appear to perform less well than babies with lower lead levels,[2] as rated by the Bayley Infants Assessments Scale. In addition, school performance is poorer among children with elevated tooth lead levels.[3] For each of these adversities, the effect appears to be proportional to dosage throughout the range of current community exposure, and the effect is present even after potentially confounding factors are accounted for. Effective action to reduce the occurrence of these adversities requires identification of the sources of lead to children.

This study was part of a longitudinal investigation of the effects of lead on infant development. It was designed to investigate the relative importance of current environmental and dietary factors in determining lead burden in a population at low risk for impaired development.

MATERIALS AND METHODS

As a result of a survey of umbilical cord blood lead concentrations from 11,837 consecutive births at the Boston Lying-In Hospital between September, 1979 and April, 1981, 249 children were enrolled in a study of lead and infant development. Subjects were drawn equally from the highest, lowest, and centermost deciles of blood lead. To be eligible for enrollment, the child must also have been expected to reside within Greater Boston (inside Route 128) for the next 2 yr in an English-speaking household, and to be free of serious medical conditions. In every case, informed consent was obtained from the parents. In general, their mothers were white (87%) and well educated (mean maternal schooling = 14.5 yr). Most children (88%) lived with both parents, and the mean maternal age was 30 yr.

Specimens of milk were collected in the homes by the mothers, on two visits (1 and 6 months post-partum) with a new, pre-cleaned, acid-washed, polyethylene, 35-ml cylinder vial with a hinged cap. Brand name and infant diet information were obtained also. If the mother was nursing, she was asked to collect breast milk directly with the vial, manually expressing the milk without any pump or other cup; if formula was being used, the mother was asked to put into the vial milk of the same dilution she used in feeding. These samples were frozen and stored at −5°C until analysis. About 30% of the mothers were given a vial in a plastic bag so that they could later collect and freeze breast milk and bring it to the hospital on their next routine visit. Although nearly all of the nursing mothers provided samples, laboratory resources limited the number of milk samples tested. Each month a random portion of those collected were measured.

Milk samples were brought to room temperature, shaken, and sonicated. Duplicate aliquots of 200 µl were digested in a microwave oven with an acid mixture under vacuum.[4] The residue was redissolved in dilute perchloric acid and the lead was measured by anodic stripping voltametry (ESA, Bedford, MS, Model 2014). Contamination during sample collection, transport, storage, and analysis was measured and found to be dominated by the sample digestion step. Using ultrapure acids the total contamination amounted to 3.3 ng/assay (*SD* = .6), which is equivalent to 1.6 µg/dl (*SD* = .3). The level of this contamination was fairly constant and it was the principal source of uncertainty in the milk lead values. This analytical blank was measured five times with each batch of 25 milk samples, and it was subtracted to give the reported values. The mean difference between duplicate samples was 1.0 µg/dl (SE = 0.2).

Lead determinations were made using umbilical cord blood of the newborns, and capillary blood lead levels were determined at 6 months of age. The method of cord blood, which uses acid digestion and the same voltametric assay as the milk samples, has been reported in detail elsewhere.[4] The capillary blood samples were dissolved with an exchange reagent, and the lead content measured with an ESA Model 3010 voltameter calibrated with the same aqueous lead standards. Blood lead results are the mean of duplicate samples. These blood lead methods were also monitored and verified throughout the study by participation in interlaboratory comparisons every 3 months. The average error of this laboratory in these trials was 2.9 µg/dl (SE = 0.6) for 25 samples. For 9 samples with blood lead less than 50 µg/dl, the mean absolute difference was 2.0 µg/dl (SE = 0.4).

Water was collected 1 and 6 months post-partem in a half-liter polyethylene, acid-washed bottle from the kitchen cold tap after about 4 L were drained. On that same day, specimens were acidified with perchloric acid to pH 1.8 and refrigerated. Lead was measured in duplicate by anodic stripping voltametry (EAS Model 2014). The 1- and 6-month values were averaged. The mean difference between duplicate samples was 0.5 µg/L. Contamination of the samples during collection, transport, and storage was measured using sham procedures and distilled water. Only 1.0 µg/L was attributable to this contamination.

Non-parametric statistical tests were employed for comparisons of groups and paired samples. Correlations were measured by distribution-free rank methods.[5]

RESULTS

The lead content of all breast milk and formulas are shown in Table 1. Their ranges overlap, and the lead concentrations do not differ significantly as judged by non-parametric Wilcoxon tests of rank scores ($P = .14$) or median tests ($P = .24$). Furthermore, among the three brands of formula used in this survey (i.e., Similac, Enfamil, and Isomil), lead levels do not differ significantly, nor are lead levels related to iron enrichment or container type (i.e., bottle or can). However, formula lead levels seen are more variable than breast milk lead levels (F-score for inequality of variance = 2.42, $P < .01$). Formula lead levels correlate poorly with infant blood lead levels ($r = .11$, $P > .1$, $N = 73$).

The lead concentrations in breast milk collected at 1 month differ minimally from those collected at 6 months; the mean difference between 20 paired samples is 0.7 µg/dl (SE = .5). Non-parametric tests reveal no differences among these two breast milk categories. Thus, lead levels in milk appear stable from 1 to 6 months. Cord blood lead correlates poorly with breast milk lead ($r = .18$, $P = .11$).

Tap water lead concentrations average 6.3 µg/L (SE = 1.4) and do not correlate significantly with breast milk, formula, or blood lead.

Table 1.—Lead Concentrations (µg/dl) in Milk, Water, and Blood Samples Obtained in Boston

Sample Type	Number	Mean	SE	Range
Breast milk	100	1.7	0.2	0–7.2
Formula milk	73	2.3	0.3	0–17.8
Tap water	249	0.6	0.1	0–34
Umbilical cord blood	249	7.2	0.3	0–25
Infant blood (6-mo)	221	6.2	0.5	0–49

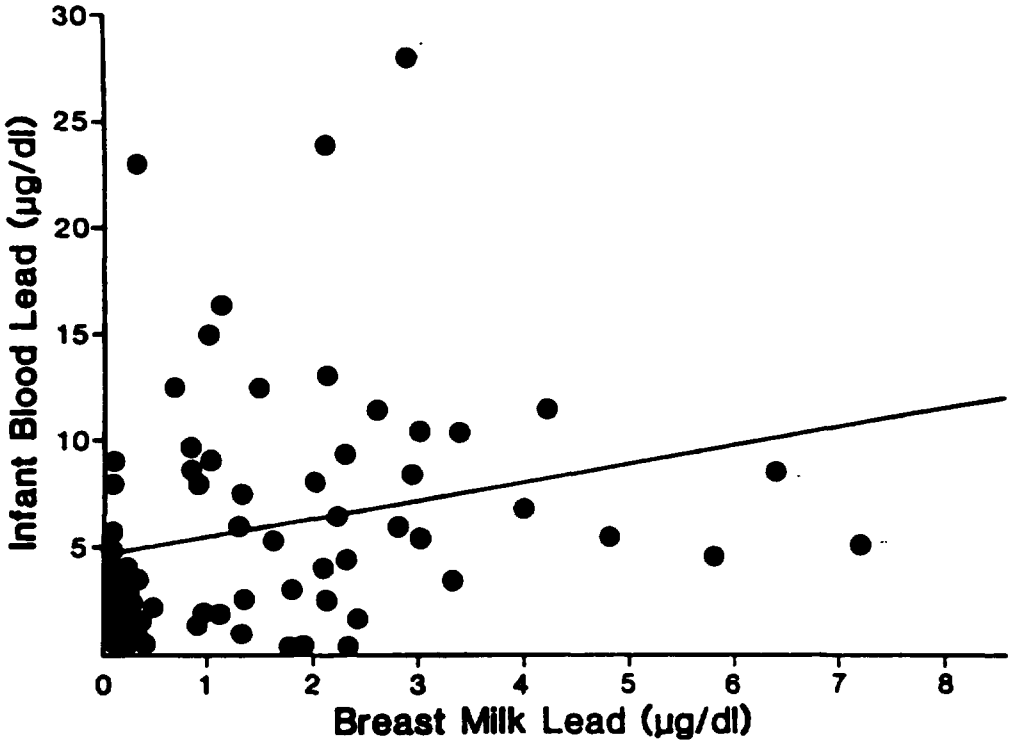

Fig. 1. Lead concentrations in breast milk and infant blood at age 6 months. There is much scatter and the distribution of the milk data is skewed. The rank correlation of milk and blood lead is highly significant (Spearman $r = .42$, $N = 69$, $P = .0003$). A linear or logarithmic model gives equivalent predictions over this range, but a curvi-linear model is needed to accommodate higher concentrations.

Blood lead levels of 6-month-old children fed formula average somewhat lower than the blood lead levels of those who were nursed: 5.6 μg/dl (SE = 0.5) vs. 7.6 μg/dl (SE = 0.6), respectively ($P = .32$ by Wilcoxon rank-sum test, or $P = .05$ by Student's t test).

Blood lead levels at 6 months of age correlate very well with dietary lead intake among the children who were nursed (Spearman, rank $r = 0.42$, $P = .0004$). Figure 1 shows that the observed values and the best (i.e., minimizing the product moment) linear fit: blood lead = 4.5 μg/dl (SE = 1.0) + 0.9 μg/dl (SE = .4) × milk lead. This model yields an r^2 of 6%, $P = .04$. If the milk lead is expressed logarithmically, which is more appropriate given the non-normal, skewed pattern of milk lead, a better fit is obtained ($r^2 = 10\%$, model $P = .009$): blood lead = 3.6 μg/dl (SE = 1.1) + 3.0 μg/dl (SE = 1.1) × Ln(1 + milk lead). The intercepts of these two models are equivalent, and they both predict nearly identical blood leads when milk are less than 6 μg/dl.

DISCUSSION

The lead content of milk and baby formulas has received considerable attention during the past decade. One issue has been the relative lead content of human breast milk compared with commercially available preparations. In this survey, commercially available formulas have lead levels similar to those of mothers' milk. The blood lead levels of the infants who received commercial preparations were insignificantly lower than those who were nursed by their mothers.

The concentrations of lead we found in breast milk are about the same as those reported previously. A nationwide sampling by Dillon, Wilson, and Schaffner,[6] nearly a decade ago, resulted in a mean of 2.6 μg/dl for 29 samples, which is very close to our values. More recently, Huat et al.[7] found mean breast milk lead levels in Malaysia to be 2 μg/dl. In 1975, Lamm et al.[8] reported that breast milk lead averaged 2 μg/dl for 7 mothers, whereas infant formula and evaporated milk had much higher levels. Ryu et al.[9] found that some commercial formula from Iowa in 1976 had markedly more lead than did breast milk. In addition, infants fed canned formula had elevated blood lead levels.

The reduction in lead content of infant formulas is attributable to improved packaging methods. Earlier soldering methods resulted in splashes of molten lead entering the can and contact between the solder and food, but the increased use of bottled formula, more careful canning techniques, and different seam designs have resulted in lower dietary lead intakes among infants.[10]

Currently, the lead content of home tap water in Boston does not contribute demonstrably to the lead intake from formulas. This may be contrasted to the situation in Scotland, for example, where higher levels of lead in drinking water, often above 100 μg/L, had been the predominant source of lead to bottle-fed infants.[11] The median dietary lead levels of 10 μg/dl and blood lead of about 18 μg/dl in Glasgow were both much higher than our findings in Boston. Our data most resemble the very lowest lead categories in Glasgow. Furthermore, combining Glasgow and Boston

data demonstrates the curvi-linear nature of the response of blood lead to dietary intake when considered over a range from 0.1 to 2–3 mg/wk.

Milk lead accounts for only 10% of the variance in 6-month blood lead levels. When environmental lead observations and personal maternal factors are also considered, 18% of the variance in cord blood lead is explained.[12] The significant covariate-adjusted predictors of cord blood lead in this same population at birth include indoor dust lead levels, smoking tobacco, drinking coffee and alcohol, parity, and maternal age. Also, monthly mean cord blood lead correlated well (product-moment $r = .76$) with monthly variations in sales of gasoline lead and indoor air lead levels.[13] If infant blood lead is adjusted for these environmental predictors, breast milk lead is still the strongest correlate of 6-month blood lead. Breast milk lead levels do not correlate significantly with any of these environmental or maternal factors and provide additional information about the child's lead exposure.

The absolute values and variances of lead in this population were so small than no health concerns were aroused.

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Requests for reprints should be sent to: Michael Rabinowitz, Lead Exposure Study, Children's Hospital, 300 Longwood Ave., Boston, MA 02115.

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